

## NISTAR Quality Report

*This report is written to describe the factors of consideration for users interesting in using the NISTAR Level 1 data product. References to datasets in the HDF files are given in the form:*

*{HDF Level (either L1A or L1B)} → {Data Group Name} → {Dataset Name}*

Before using NISTAR data, please note the following:

- The filtered data is not corrected for the filter transmission coefficient. The issue is described in Section I. Comparing different channels accurately is not possible without this correction.
- Due to signal noise, the radiometer data should be smoothed with a filter of the user's choice. It is recommended to use an averaging of at least two hours. Resolving actual Earth signal variation on a finer time grid is not possible; however, the full time resolution data is provided to allow the user to apply a filter of their choosing. The issue is described in some detail in Section II.

### I. Filter Transmission Correction

The NISTAR Level 1B (L1B) Earth Irradiance data product has incorporated many calibration steps, including the application of the phase-sensitive demodulation algorithm, a dark background offset, and an absolute scale (relative responsivity) correction. However, one very important step remains to accurately compare irradiances from different radiometer channels: the filter transmission. The absolute scales of the filtered channels are not valid until the filter transmission correction is made. A spectral transmission curve is given for each of the six filters (three Band B/Solar Reflected and three Band C/Solar Reflected less UV-VIS) across the entire spectral band of interest. This data can be found in the HDF files in the Ground\_Calibration group under the dataset FilterTransmissionCurves. Note that in this dataset, 1C1 is the filter in front of receiving cavity 1 (RC1) and 7B1 is the filter in front of RC3 during normal operations (filter motor position 3). The table in L1A or L1B → Ground\_Calibration → FilterPositions lists the filters in front of each detector vs filter motor position.

In order to correct for the transmission losses, this spectral transmission curve must be weighted by the spectral distribution of the irradiance source (the Earth) and then averaged. The spectral irradiance distribution of the Earth is time and scene dependent and must be determined from outside sources, such as EPIC and other Earth-observing satellites. There is a different spectral distribution for a clear vs. cloudy scene or an ocean- vs. land-dominated scene. Due to this time-dependence, the filter transmission cannot be corrected for during NISTAR level 1 processing, and the task is left for level 2 users who can incorporate data from other instruments and satellites.

Figure 1 and Figure 2 below give the spectral transmission function for the two filters most commonly used, 7B1 and 1C1. The B filter data results from ground piece-parts (each filter individually, prior to integration into the instrument) testing done in 1999 at the National Institute of Standards and Technology (NIST), scaled by the low-resolution 2013 system-level measurements to account for changes during instrument refurbishments. The C filter data results from ground system-level testing

done in 2010 at the NIST Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources (SIRCUS) facility using a tunable laser, also scaled by the 2013 data.

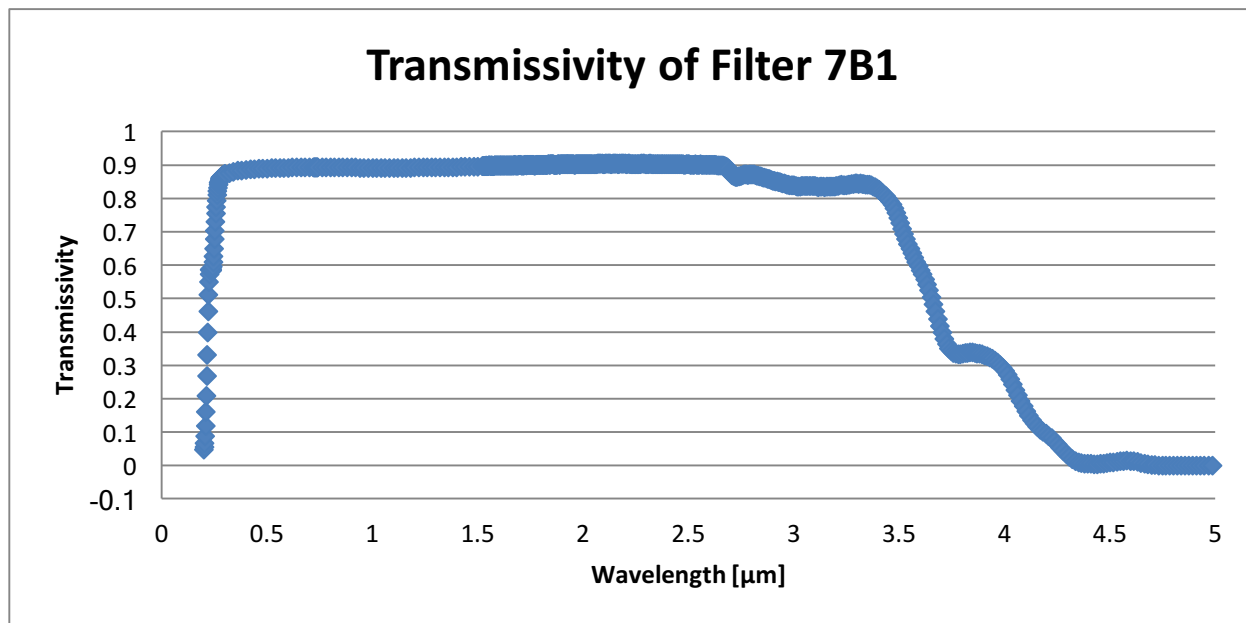


Figure 1: Spectral transmission curve for the 7B1 filter, which is in front of Receiving Cavity 3 during normal operations.

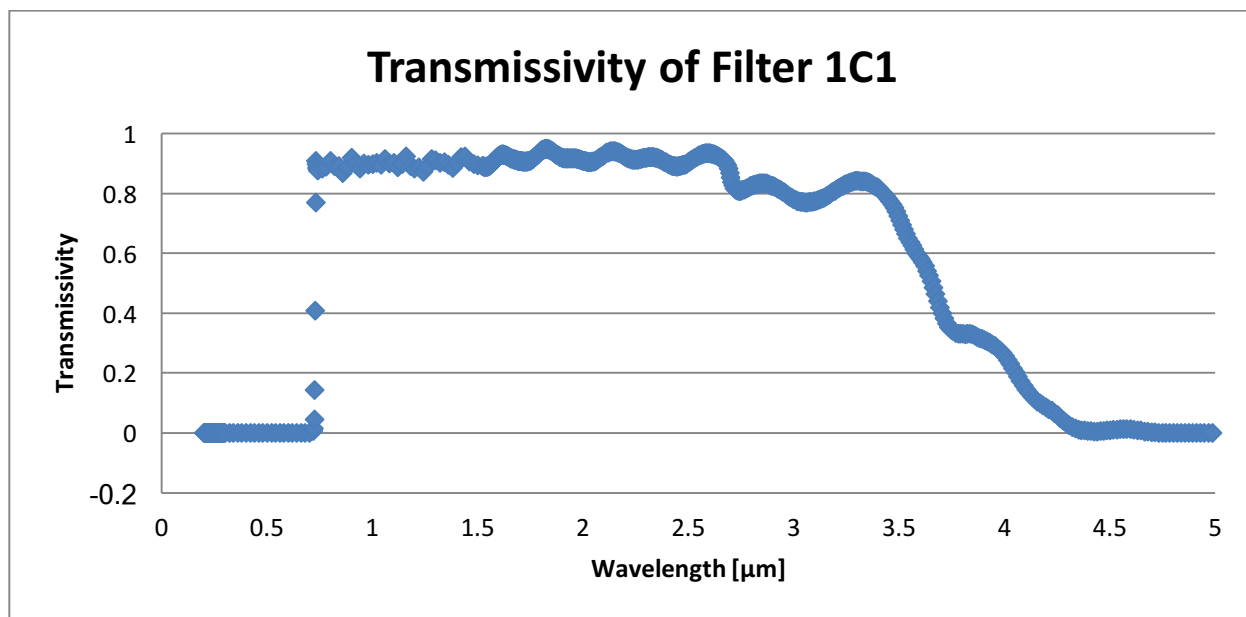


Figure 2: Spectral transmission curve for the 1C1 filter, which is in front of Receiving Cavity 1 during normal operations.

## II. Uncertainty Budget

Table 1 below gives a summary of the NISTAR uncertainty estimates for each of the three channels for a daily mean measurement, given as percentages of the mean Earth power measurements for the respective channels:

Channel	Dark Offset Measurement (%, k=1)	Absolute Scale from Ground Tests (%, k=1)	Filter Transmission (%, k=1)	Total (%, k=1)
Total Channel	1.4	0.3		1.4
Solar Reflected	4.3	0.3	3	5.3
Solar Reflected less UV-VIS	11	0.3	3	11.4

Table 1: NISTAR Uncertainty Budget Overview

The NISTAR measurement uncertainties are dominated by the on-orbit signal-to-noise ratio.

The Dark Offset Measurement provides the background thermal loss to space of the detectors and must be interpolated from the monthly Dark Space Calibrations to each Earth observation. The Dark Offset Measurement uncertainty percentages above incorporate both the signal noise as measured during these calibration activities and the error introduced via the interpolation to the Earth observations.

The Absolute Scale was derived during ground tests with k=1 uncertainty of less than 0.3%. The post-calibration degradation has been minimal. The on-orbit measurements of relative responsivity between the detectors vary on a scale within this 0.3% uncertainty, validating that the irradiance scale was transferred from ground to orbit.

The filter transmittances were measured across the full spectrum during piece-part ground calibration at NIST. In 2010 and again in 2013 after instrument refurbishment, the filter transmittance was measured at a handful of laser wavelengths and a scaling coefficient was derived to transfer the NIST data forward. The 2013 measurements themselves have a sub-percent uncertainty, and the uncertainty in scaling the full spectral data is estimated to be at 2-3%. The total channel has no filter and thus there is no contribution to uncertainty from the filter transmission.

It should also be noted that one-off events, such as the monthly Magnetometer X-Axis Roll, can disrupt NISTAR accuracy for a period of time.

Due to the level of noise present, it is not recommended to use the data to resolve signal variations on a time scale finer than about two hours. The full time resolution data (1 second) is provided to allow the user to choose a data reduction technique which they deem most appropriate. In addition, four-hour boxcar means (on an hourly time resolution) and daily means are provided in the Level 1B product.

### III. Poor Quality Data Time Periods

There are a number of periods of time during the lifetime of NISTAR where the data quality is not adequate for science products. The primary reasons include calibration activities, anomalies, and lack of a suitable dark offset measurement. The Level 1B data product automatically time periods which are not at nominal operating configuration (Filter position 3, Earth completely within instrument field of view). The remaining sections which are not considered science worthy are tabulated (see: L1A or L1B → On-orbit\_Calibration → PoorQualityData). The final Level 1B product ignores these time periods as well.

When encountering a section of missing L1B data where the raw data (L1A → Science\_Data → ScienceData) was present, it has likely been filtered out during processing. In this case, the missing data can be found in the intermediate products, such as the L1B → Demodulated\_Power → Demodulated\_Radiometer\_Power. This data should be used only with care and an understanding of why the data was filtered during processing. The user can consult the NISTAR Activity Timeline document for hour-by-hour data quality reporting.

### IV. “Real Time” Processing Lag

There are a few calibration tables which are updated periodically and rolled into the L1B processing algorithms, particularly the dark background radiometer measurements (see: L1A or L1B → On-orbit\_Calibration → RadiometerDarkPower). Current operations of the instrument include monthly dark space calibrations, which are used to subtract the background heat loss to space term from the Earth irradiance measured.

Background measurements corresponding to each Earth observation must then be interpolated from these monthly calibration activities. To avoid extrapolations, NISTAR processing should lag behind real-time processing by about one month.

### V. Operating Mode Changes

There have been many operating mode changes during the lifetime of NISTAR, in particular the shutter cycle period length. These changes were made in efforts to optimize instrument performance. It is not recommended to compare raw radiometer data across these operating mode changes. Careful effort has been made to use appropriate dark offsets such that the final L1B product, the Earth signal irradiances, can be used to compare data of varying shutter cycle period length.

## VI. VC0 / VC1 Data Rate Switches and “Decimated” Data Products

When the spacecraft is in real time contact with the ground, data is generated at the maximum data rate. This data is said to be made available through Virtual Channel 0 (VC0). The data rate is 1 Hz (one data packet per second) for Science data (AppID 82) and Miscellaneous data (AppID Misc), 0.1 Hz for Engineering data (AppID 86), and 1/30 Hz for Thermistor data (AppID 37). In addition, data is stored continuously in onboard memory to ensure data coverage during the back orbit. This data is transmitted through Virtual Channel 1 (VC1). VC1 data is available during real time contacts as well, but is duplicated within the VC0 data. Due to limited onboard memory, the VC1 science data is filtered to 1/6<sup>th</sup> of the nominal cadence.

On July 27<sup>th</sup>, 2016 DSCOVR became the primary operational solar weather spacecraft, replacing Advanced Composition Explorer (ACE), and received 24 hour ground support. Prior to this, VC0 data was only available when the US-based ground tracking stations had visibility of DSCOVR. The issue was most critical during winter months when there was less visibility of the spacecraft from the Northern Hemisphere ground stations, and therefore less availability of VC0 data. After the transition date of July 27<sup>th</sup> of 2016, VC0 data was available nearly 24 hours, with some small gaps remaining in the peak of winter and occasional drops near transitions between ground stations.

The lack of VC0 data presents an issue for processing of the data. When the shutter is in autcycle on mode (oscillates between open and closed with a fixed period), the demodulation (amplitude extraction) of the radiometer power signal relies on an accurate knowledge of the number of samples per shutter cycle. The period of the shutter motions is computed via a Fourier analysis of the input power signal. If the number of samples per cycle changes during a day of processing the demodulation will lose accuracy and usefulness near these transitions. The switches between VC0 and VC1 data rate (Figure 3) cause such a problem, and the processing software treats these data rate transitions carefully.

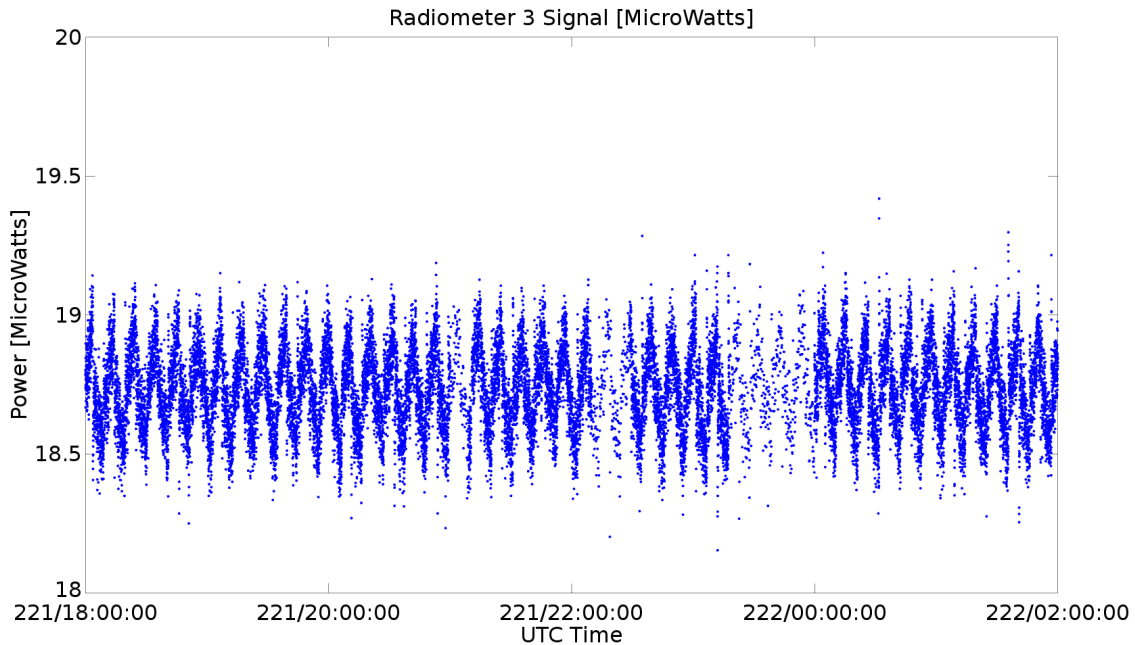


Figure 3: Radiometer Data from DOY 221, 2015 showing data rate switches

The workaround involves two streams of data through Level 1A and 1B processing, the nominal data and the “decimated” data. The nominal data is maintained at the best available data rate. The decimated data is forced, when needed, to the VC1 1/6 Hz data rate by eliminating data points. The sacrifice of data resolution allows for a much more accurate and reliable computation of the demodulation on days with date rate variability. During Level 1B (L1B), there are corresponding data products for both the nominal and the decimated data sets, see Figure 4 and Figure 5 below. The left plots in blue are the raw power signal, and the right plots in red are the resulting demodulated power signal for each radiometer.

It is recommended to use the nominal (higher time resolution) data when available, and the decimated data otherwise. It is expected that the decimated data products will suffer from decreased signal-to-noise ratios.

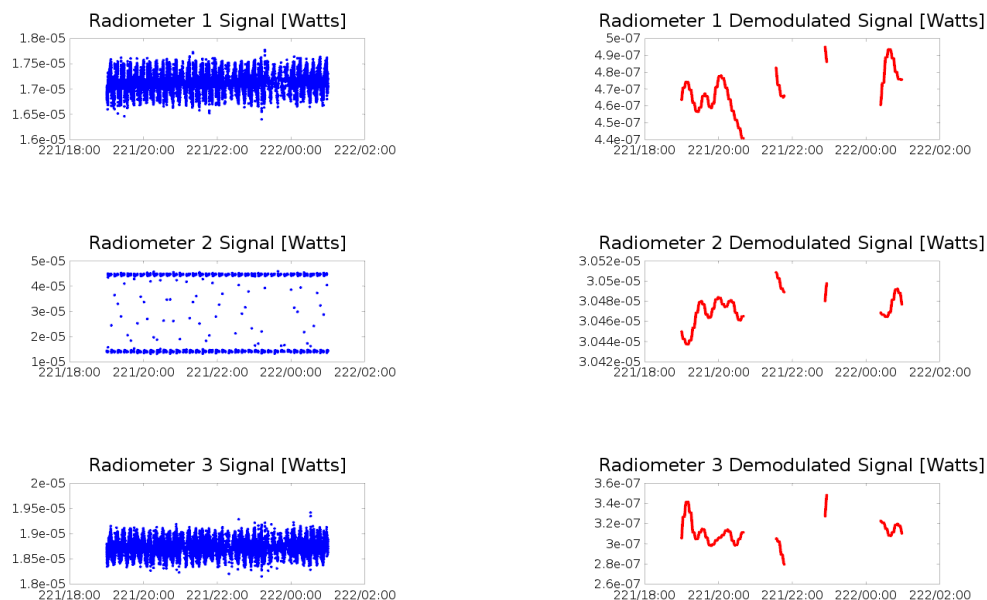


Figure 4: Nominal L1B data products for DOY 221, 2015 without decimation. Gaps are due to lack of VC0 data.

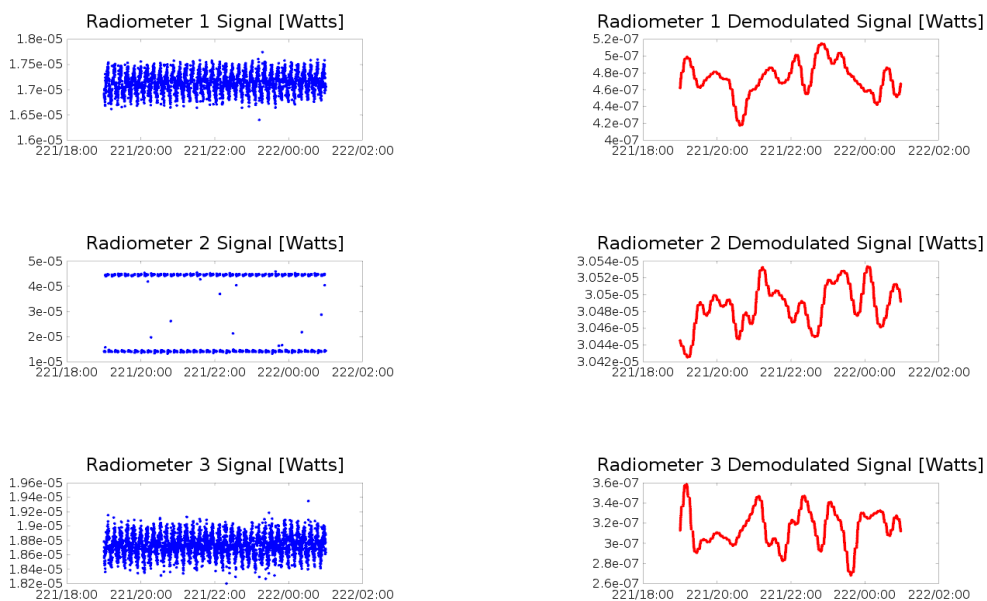


Figure 5: Decimated L1B data products for DOY 221, 2015 at the VC1 data rate. There are no gaps due to lack of VC0 data.

## VII. NISTAR Timing Anomaly

An anomaly was first detected by looking at the shutter period. When the instrument was commanded to have a shutter period of exactly ten minutes (600 seconds), the observed behavior was a shutter period of 638 seconds. A similar ratio was seen when the shutter period was changed to 4, 20, 30, and 40 minutes. An investigation into the discrepancy revealed a phenomenon referred to as the NISTAR Timing Anomaly. The symptoms of the anomaly are:

- the discrepancy between commanded and observed shutter period,
- 6-8% of science and engineering telemetry is repeated from the previous record,
- science data can be more than two seconds older than the reported timestamp,
- engineering data can be more than 20 seconds older than the reported timestamp,
- muddled shutter transitions due to the repeated telemetry, and
- shutters becoming uncalibrated due to a race condition stemming from the timing issue.

The cause of the anomaly is an unreliable 400 Hz clock rate on the NISTAR flight software (FSW). A counter corresponding to each process counts down (with respect to the 400 Hz clock) and generates a system interrupt when the counter hits zero. The interrupt callback function adds the period (in the case of science data, 1 second) to the counter and notifies the operating system that a tick occurred. The function will continue adding the period until the counter goes positive (this would occur if a tick was missed and not serviced within the period). In the case of a missed tick, the FSW sees two ticks together but, due to a FSW bug, the NISTAR scheduler only learns about one of them. The net effect is that some ticks are dropped entirely (6-8% of the time) and others are serviced irregularly. The CompHub (the spacecraft computer) reads NISTAR science data at a rate that is very close to 1 Hz. If the data has not been updated by NISTAR, the CompHub essentially re-reads the same old telemetry creating a duplicate.

Correcting the FSW architecture so that the missed ticks are handled properly by the scheduler is not possible, or at least the risks are too high to make it a practical option. The clock rate is burned into the FSW, and it would have a large ripple effect to attempt rebuilding it. The chosen option was to mitigate the impact through creative ground processing. The most critical impact from the anomalous behavior is that the shutter transitions from open to closed are muddled by the duplicated telemetry. Physically, it takes one to two seconds for the shutter to move from open to close, but the duplicated telemetry can report telemetry which is more than two seconds old and smooth the shutter transitions. The demodulation algorithm of the radiometer signal relies on an accurate knowledge of the number of samples per cycle. The muddled shutter transitions create non-physical noise in the demodulation of the signal unless handled in some special way. Shutter transitions are further complicated by the VC0 drop outs described in the previous section. The decreased resolution (1/6 Hz) of the VC1 data leads to more poorly resolved shutter transitions.

The workaround involves a new algorithm referred to as “manual demodulation”. The algorithm begins as normal, by computing the number of samples per cycle. It then forces the samples per cycle to be one of a hard coded set of possible values, one for each of the operating shutter periods used during the



mission: 4, 10, 20, 30, and 40 minutes. This is accomplished by detecting shutter movements and only retaining the specified number of points for each shutter cycle. For thermal reasons, the data is chosen from the latter portion of each shutter half-period. Finally, the demodulation is done using this new signal which has an absolutely constant shutter period, equal to some specified percentage of the original period. It has an additional benefit of only using data which are closer to thermal equilibrium. The result is a piecewise demodulation output which has a portion of the data missing, but is a much more accurate measurement of the amplitude of the radiometer signal.

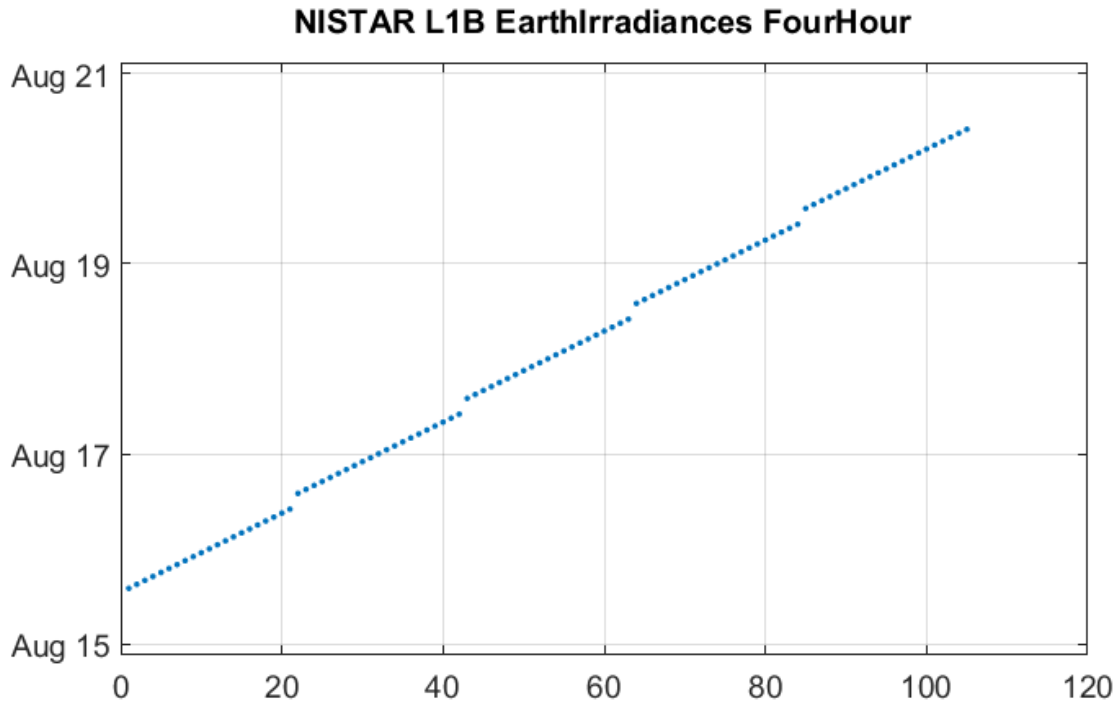
At the shorter autocycle period of 4 minutes, it was deemed that the manual demodulation algorithm was neither necessary nor preferable; thus, the full dataset was to be used for demodulation. This is due to the improvement in the thermal response of the instrument by optimizing control parameters, as well as fewer VCO dropouts. In addition, losing data points is more costly when there are fewer of them per shutter cycle.

## Notice for Users of NISTAR L1B Data Products

The DSCOVR Science Team has recently noticed an issue regarding the time stamps in particular datasets of the NISTAR L1B data products, where the DSCOVR Epoch time does not yield a smooth and continuous progression. To be specific, we have categorized this issue into two types, based on different behavior and datasets.

1. **Binned\_Averages/EarthIrradiances\_FourHour**  
**Binned\_Averages/EarthIrradiances\_FourHour\_Decimated**

The time stamps yield a jump in between two consecutive Julian Days, which means the data points are not averaged evenly in time.



## 2. Demodulated\_Power/Demodulated\_Radiometer\_Power

Demodulated\_Power/Manual\_Demodulated\_Radiometer\_Power

Demodulated\_Power/Demodulated\_Radiometer\_Power\_Decimated

Demodulated\_Power/Manual\_Demodulated\_Radiometer\_Power\_Decimated

Earth\_Irradiance/RC1\_Earth\_Signal\_Irradiance

Earth\_Irradiance/RC2\_Earth\_Signal\_Irradiance

Earth\_Irradiance/RC3\_Earth\_Signal\_Irradiance

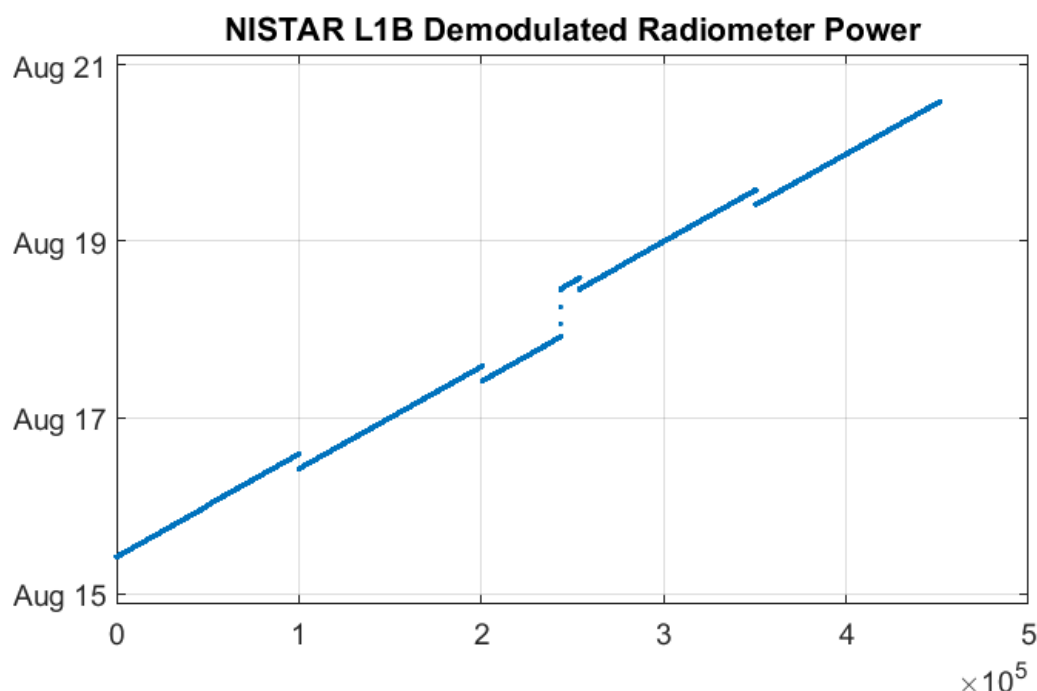
Earth\_Irradiance/RC1\_Earth\_Signal\_Irradiance\_Decimated

Earth\_Irradiance/RC2\_Earth\_Signal\_Irradiance\_Decimated

Earth\_Irradiance/RC3\_Earth\_Signal\_Irradiance\_Decimated

The time stamps yield overlaps (“jump backwards”) in the above datasets. Technically this is caused by data redundancies, i.e., the current dataset always contains the last part of previous day’s data.





The precise cause of timing overlaps has been identified. The L1B processing reads the output of L1A processing and demodulates the irradiance data with the referencing square wave of shutter autcycles. However, the demodulation processing will zero out the first and the last 2 autcycle periods of data in the time series. To compensate this artificial effect, L1B processing reads the data of the current day, and additional 2 hours data from the days before and after at both ends. Therefore, each L1B output file includes demodulated irradiance data of 28 hours minus 2 shutter cycles at both ends.

To avoid this timing redundancy, DSCOVER Science Team may update the future L1B product versions to implement additional truncation process to trim the data. Currently, users should make sure to read the time stamps in the DSCOVERepochTime field, found within each NISTAR L1B HDF data group, and filter the duplicate data as necessary.

DSCOVER/NISTAR Science Team  
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